ADVANCED RESEARCH PROJECTS AGENCY

Order No. 455

OFFICE OF NAVAL RESEARCH

Contract Nonr-1866(49)/NR-015-807

441295

PROJECT DEFENDER

Semiannual Technical Summary Report

Covering Period: December 1, 1963 - June 1, 1964

DIVISION OF ENGINEERING AND APPLIED PHYSICS
HARVARD UNIVERSITY - CAMBRIDGE, MASSACHUSETTS

Office of Naval Research

Contract Nonr-1866(49)

NR - 015 - 807

ARPA Order No. 455

SEMIANNUAL TECHNICAL SUMMARY REPORT

Covering Period December 1, 1963 - June 1, 1964

The research reported in this document was made possible through support extended the Division of Engineering and Applied Physics, Harvard University, by Project DEFENDER under the joint sponsorship of the Advanced Research Projects Agency, Department of Defense and the Office of Naval Research, Department of the Navy. Reproduction in whole or in part is permitted for any purpose of the United States Government.

Submitted by:

N. Bloembergen, Project Director

Cruft Laboratory

Division of Engineering and Applied Physics

Harvard University

Cambridge, Massachusetts

SEMIANNUAL TECHNICAL SUMMARY REPORT

Covering Period December 1, 1963 - June 1, 1964

Personnel

Prof. N. Bloembergen	Project Director
Dr. J. Ducuing	Research Fellow
Dr. J. vander Ziel	Research Fellow
Mr. R. Chang	Graduate Student
Mr. P. Lallemand	Graduate Student
Mr. L. Malmstrom	Graduate Student

SEMI-ANNUAL TECHNICAL SUMMARY REPORT

Covering Period December 1, 1963 - June 1, 1964

Synopsis

The nonlinear optical constants of several III-V semiconductor compounds have been determined at $\lambda = 1.06$ microns with a neodymium glass laser, to supplement the data taken with the ruby laser. Dispersive properties of the nonlinear susceptibility have been established.

The coupling between vibrations and light waves in Raman laser media has been studied theoretically. Some new results have been reported in the May 4, 1964 issue of the Physical Review Letters.

The experimental set-up has been built to send a laser beam and a Stokes beam of separately controlled intensity and direction through a thin sample cell. In this manner, accurate measurements of the Stokes gain as a function of angle, polarization and intensity of the laser beam will be made possible. The same method can be extended to the measurement of anti-Stokes gain.

A. Nonlinear optical constants of III-V compounds

The measurement of the second harmonic production in reflection from Ga As, Ga Sb, In As and In Sb single crystals has been extended to a longer wavelength by the use of a neodymium glass laser. The nonlinear susceptibility is found to be twenty to fifty percent smaller at $\lambda = 1.06$ microns then at $\lambda = 0.694$ microns. This result can be understood on the basis of theoretical expressions for the nonlinearity in the presence of band absorption

at the fundamental and/or second harmonic frequency. The case of GaAs is especially interesting, because the laser at $\lambda = 1.06\mu$ is not absorbed. In this case, the nonlinearity can also be determined from second harmonic production in transmission . This result agrees with the reflection measurement. The transmission method is, however, less accurate, because it depends more sensitively on the difference in the linear dielectric constants at the fundamental and second harmonic frequency. The nonlinear susceptibility does not change drastically as the fundamental frequency is varied from just above to just below the absorption edge. An order of magnitude change in the nonlinearity is expected to occur when the second harmonic frequency is varied across the gap.

This material has been presented at the March 1964 meeting of the American Physical Society in Philadelphia, Pennsylvania, and has been accepted for presentation at the International Semiconductor Conference, to be held in Paris, July 20 - 24, 1964. An invited paper was given before the Optical Society of America, April 2, 1964 in Washington, D. C.

B. Theory of nonlinear Raman-type susceptibilities

The coupling between laser, Stokes and anti-Stokes light waves and the molecular vibrations in Raman laser media has been investigated theoretically. A careful analysis of the coupled wave equations shows that neither the Stokes nor the anti-Stokes wave has an exponential gain factor in the direction of exact momentum matching. On either side, just off this direction, exponential gain for one wave with a mixed Stokes-anti-Stokes

character occurs due to parametric coupling with the laser beam. These interesting conclusions have been reported [1] and further details may be found in this reference.

The theory is being extended to the case of higher order Stokes and anti-Stokes frequencies. Furthermore, it has been found, experimentally as well as theoretically, that depletion of the laser beam plays an important role. The laser field must not be treated as a fixed parameter and the wave at the laser frequency should be included explicitly in the set of coupled amplitude equations. Numerical work on this nonlinear problem is now in progress.

C. Experimental measurement of Stokes and anti-Stokes gains

The theoretical considerations have helped to design an experimental arrangement for reliable measurements of Stokes and anti-Stokes gains. A Q-switched ruby laser beam is split into two beams of about equal intensity by a beam splitter. One beam creates Stokes light in a Raman cell. With the aid of two selective dielectric mirrors this Stokes beam is superimposed on the other laser beam. By rotation of one of the mirrors the angle between the laser and the Stokes beam can be varied. The intensity and polarization of either beam can be adjusted independently by suitable absorbers. The superimposed beams pass through a second Raman cell, the length of which is chosen so that the gain in this cell is about a factor of three or less. Preliminary tests have confirmed the usefulness of this scheme. Reliable measurements of the Stokes and anti-Stokes gains in a number of liquids will be carried out in the next period.

D. The inverse Faraday effect

When an intense circular polarized light beam passes through a transparent medium, a dc magnetization is produced along the direction of propagation. This is the magnetic analogue of the dc rectification of light, reported by Franken [2]. As this latter effect may be regarded as the thermodynamic inverse of the linear electro-optic Kerr effect, so can the dc magnetization be considered and calculated as the inverse of the Faraday effect [3] .

A circular polarized Q-switched ruby laser beam falls on a CaF_2 crystal doped with rare-earth ions, e.g., Eu^{2+} . A pick-up coil followed by a wide band amplifier detects the magnetization pulse produced by the light pulse. Preliminary experiments have indeed shown the presence of a signal, the sign of which depends on the sense of circular polarization of the laser beam. The dependence of this signal on concentration and nature of the paramagnetic ion, on temperature, and on a dc magnetic bias field is at present under investigation.

References

1. N. Bloembergen and Y. R. Shen, Phys. Rev. Letters 12, 504 (1964).
2. M. Bass, P. A. Franken, J. F. Ward, and G. Weinreich, Phys. Rev. Letters 9, 446 (1962).
3. P. S. Pershan, Phys. Rev. 130, 919 (1963).

Director [2]
Advanced Research Projects Agency
The Pentagon
Washington 25, D. C.

Battelle Memorial Institute
505 King Avenue [2]
Columbus 1, Ohio
Attn: Battelle-DEFENDER

Office of Naval Research
Branch Office [2]
495 Summer Street
Boston, Massachusetts 02110

Defense Documentation Center
Cameron Station [2]
Alexandria, Virginia 22314

Office of Naval Research
Department of the Navy [2]
Washington, D. C. 20360
Attn: Code 421

Office of Naval Research
Department of the Navy [2]
Washington 25, D. C.
Attn: Project DEFENDER

Director
U. S. Naval Research Laboratory
Technical Information Officer
Code 2000, Code 2021 [2]
Washington 25, D. C.

Director
Research Department
U. S. Naval Ordnance Laboratory
White Oak
Silver Spring, Maryland 20910

Air Force Office of Scientific Research
Attn: SRPP
Washington, D. C. 20333

Dr. F. K. Willenbrock, Dean
Div. Eng. and Applied Physics
Pierce Hall
Harvard University
Cambridge, Massachusetts 02138

Gordon Mc Kay Library
Pierce Hall [2]
Harvard University
Cambridge, Massachusetts 02138
Attn: Technical Reports Collection

Editorial Office [4]
Pierce Hall 210
Harvard University
Cambridge, Massachusetts 02138
Attn: Technical Reports Reserve

Prof. N. Bloembergen
Pierce Hall 231
Harvard University
Cambridge, Massachusetts 02138
[Remaining copies]

- - - - - - -

*One copy to each address, unless otherwise indicated by numbers enclosed in brackets.

UNCLASSIFIED

UNCLASSIFIED